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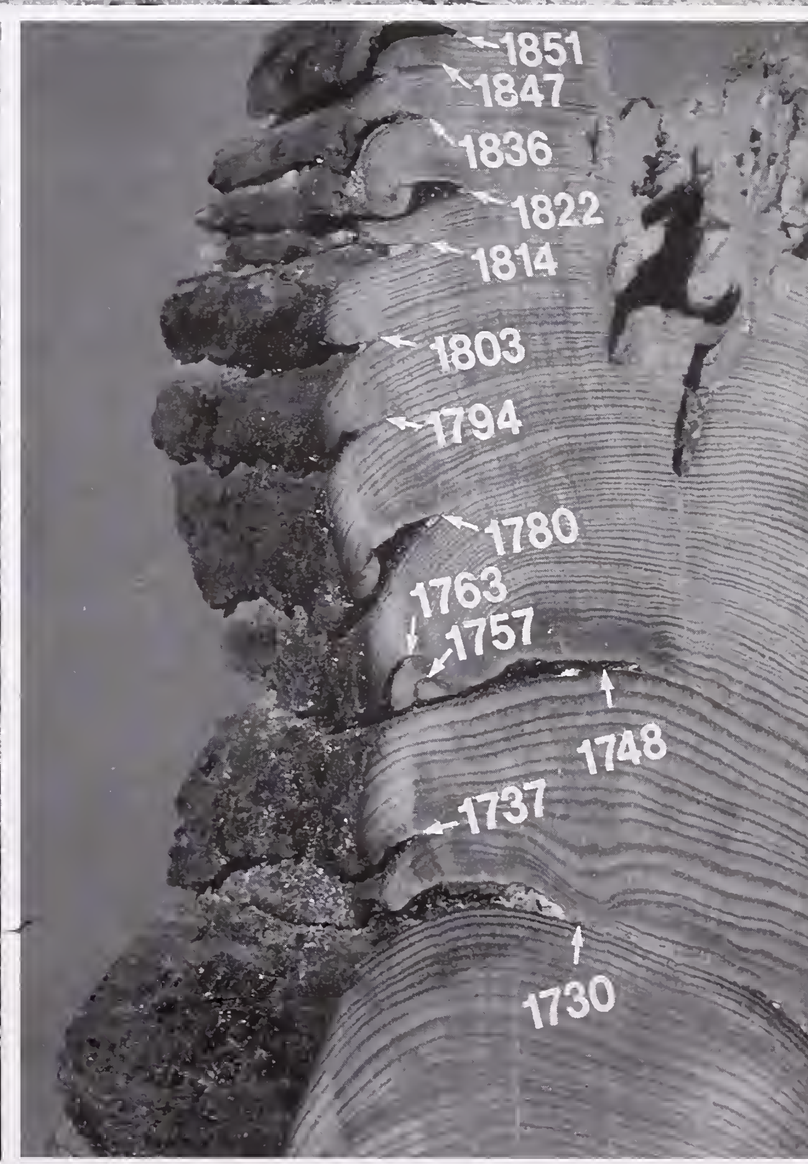
RM-RP-330**

Interactions of Fire Regimes and Land Use in the Central Rio Grande Valley



Abstract

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Four centuries of land use history were compared to fire regime characteristics along a use-intensity gradient. Changes in intensity and type of utilization varied directly with changes in fire regime characteristics near population centers, while remote areas showed little effect. Changes in fire frequency and fire-climate relationships during some periods suggest that humans augmented "natural" fire associated with lightning ignitions. Our results show that human alterations in fire regime characteristics can be documented and, in some cases, can be distinguished from pre-existing conditions dominated by physical and biological processes that operate independently of human cultural effects. Results also support the view that pre-20th century human impacts on landscapes were localized and episodic, rather than regional and constant.

Keywords: dendrochronology, fire history, land-use history, climatic change, livestock grazing, human ecology.

The Authors

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Front cover: *Embach sheep grazing in ponderosa pine forest (photo courtesy of Northern Arizona University, Cline Library, Arizona Wool Growers Collection, NAU PH 84.1.78). Photos of fire–scarred tree and tree cross section with fire dates by Chris Baisan.*

Interactions of Fire Regimes and Land Use in the Central Rio Grande Valley

Christopher H. Baisan and Thomas W. Swetnam

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Interactions of Fire Regimes and Land Use in the Central Rio Grande Valley

Introduction

Although forest fires are popularly regarded as agents of destruction, in an ecological context they function both as a renewing force and as an essential means of recycling biomass. Fire plays a critical role in stabilizing ecosystems, particularly in semi-arid systems where rates of biomass accumulation exceed the normal rates of decay. Natural vegetation complexes that currently occupy New Mexico landscapes have developed under the influence of fire and climate over the past 10,000 years (Anderson and Shafer 1991, Betancourt et. al. 1990). Some of these vegetation types depend completely upon fire for their existence, and many individual species are considered fire-adapted or fire-dependent. Evolutionary adaptations are products of millions of years of selective pressure and are evidence of the co-evolution of these organisms with natural disturbances such as fire (Wright and Bailey 1982).

In this paper, we present evidence of dramatic modifications of pre-existing ecological systems by human activities. Numerous authors, including Dobyns (1978), Pyne (1982), Bahre (1985, 1991), and MacCleery (1994), have suggested that humans modified the structure and composition of vegetation over large areas of the pre-20th century Southwestern landscape, especially by the use of fire. Our research group at the Laboratory of Tree-Ring Research has conducted extensive studies of fire history in forested ecosystems at more than 60 sites throughout Arizona and New Mexico (Swetnam and Baisan 1996). Our studies suggest that most of these areas existed in a semi-natural state, little affected by human populations, before the introduction of large numbers of livestock around the turn of the 20th century. Natural dynamics of biomass accumulation, climatic regimes, and lightning ignitions can account for fire frequencies documented at most sites studied. Human economics dictate that significant environmental modifications are limited by population sizes and resource needs. Thus, recognizable human impacts before the 20th century were probably limited to high use areas and high value resources.

Evidence in the current study represents a special case in which natural dynamics fail to provide an adequate explanation for some of the patterns observed. The results stand out in contrast to those of most of our previous studies. Recent work in the Rincon Mountains (Baisan 1990), Jemez Mountains (Touchan et. al. 1995), the Chuska Mountains (Savage and Swetnam 1990), and Chiricahua National Monument (Swetnam et al. 1991) also supports the idea that human influences can be recognized as a deviation from long-term natural dynamics in certain places and times.

Setting

The central Rio Grande valley in the vicinity of Albuquerque, New Mexico (figure 1), presents a striking physical setting. Bounded on the east by a string of fault block mountains rising almost a mile above the valley floor, the basin follows a structural rift dotted with volcanic features (Kelly and Northrop 1975). A flat plain, broken only by scattered ranges, extends to the west, increasing the contrast with the uplift to the east. The physical setting and natural resources of the area have attracted human populations for at least the last 10,000 years. The great topographic relief, juxtaposed with the perennial flow of the Rio Grande, results in the concentration of a wide variety of resources within a relatively small area. The semi-arid climate of the region makes this concentration particularly attractive to people, and archaeological investigations have documented the nearly continuous presence of human settlements in the vicinity of the modern city of Albuquerque over the past two millennia (Cordell 1979).

Vegetation assemblages found here range from grassland and riparian communities along the Rio Grande valley to spruce-fir forests, aspen stands, and alpine tundra in the higher mountains. Pinyon-juniper woodlands cover large areas at intermediate elevations. Great diversity in micro-environments related to elevation, aspect, soils, and topography results in a high diversity of plant associations and habitats (Dick-Peddie 1993).

The climate of this region is characterized by high temporal variability. Summer rains are spatially variable as well. Annual rainfall at Albuquerque over the last century has ranged from a low of 84 mm in 1917 (the second lowest being 1989, with 94 mm) to 404 mm in 1941, with a mean of 213 mm (figure 2). Mean monthly temperatures typically range from 1°C in January to 25°C in midsummer. Albuquerque receives small amounts of precipitation as snow during the winter, while the crest of the Sandia Mountains may receive as much as 3 m. Figure 2 shows the monthly means and extremes of precipitation and temperature for Albuquerque, as well as data from

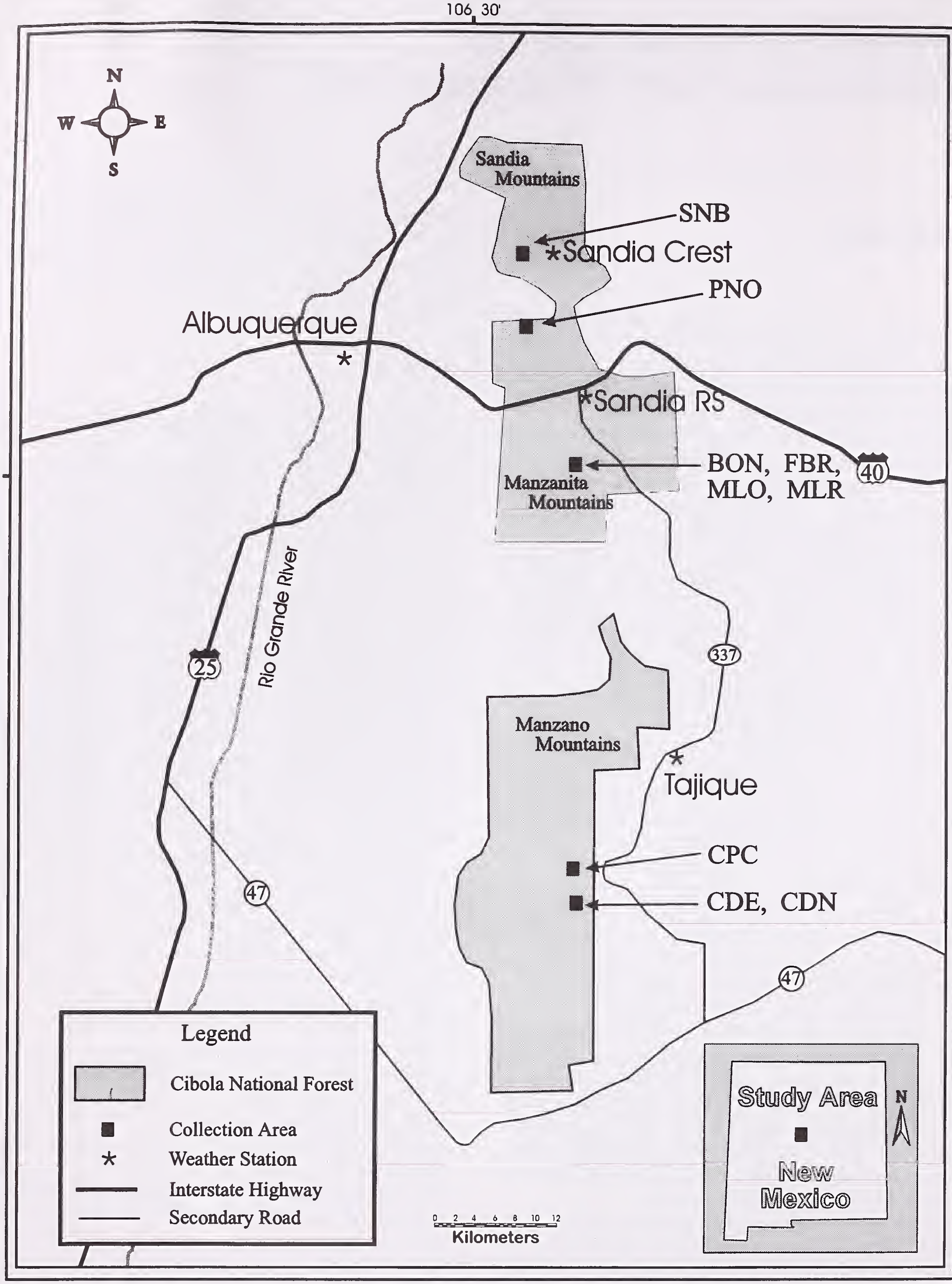


Figure 1. Central Rio Grande valley of New Mexico, with locations of collection sites and weather stations noted.

Sandia Crest, Tijeras Ranger Station, and Tajique. Precipitation reaches this area in the form of frontal storms migrating off the Pacific Ocean during the winter months, while moist air masses originating over the Gulf of Mexico and the eastern Pacific generate convective storms in the summer. Synoptic-scale features such as the El Niño-Southern Oscillation (ENSO) may significantly affect year-to-year variability in precipitation, emphasizing connections between regional climate and hemispheric-scale processes (Andrade and Sellers 1988, Harington et al. 1992).

Fires generated by lightning occur during the summer months, particularly from May through July, when "dry" thunderstorms often produce lightning but little rain. Thirty years of USDA Forest Service fire data show an annual average of two lightning fires per year for the Sandia Mountains, with a range of zero to nine, while the Manzanita Range has an average of 0.3 ignitions per year (figure 3). No data were compiled for the southern Manzano Mountains.

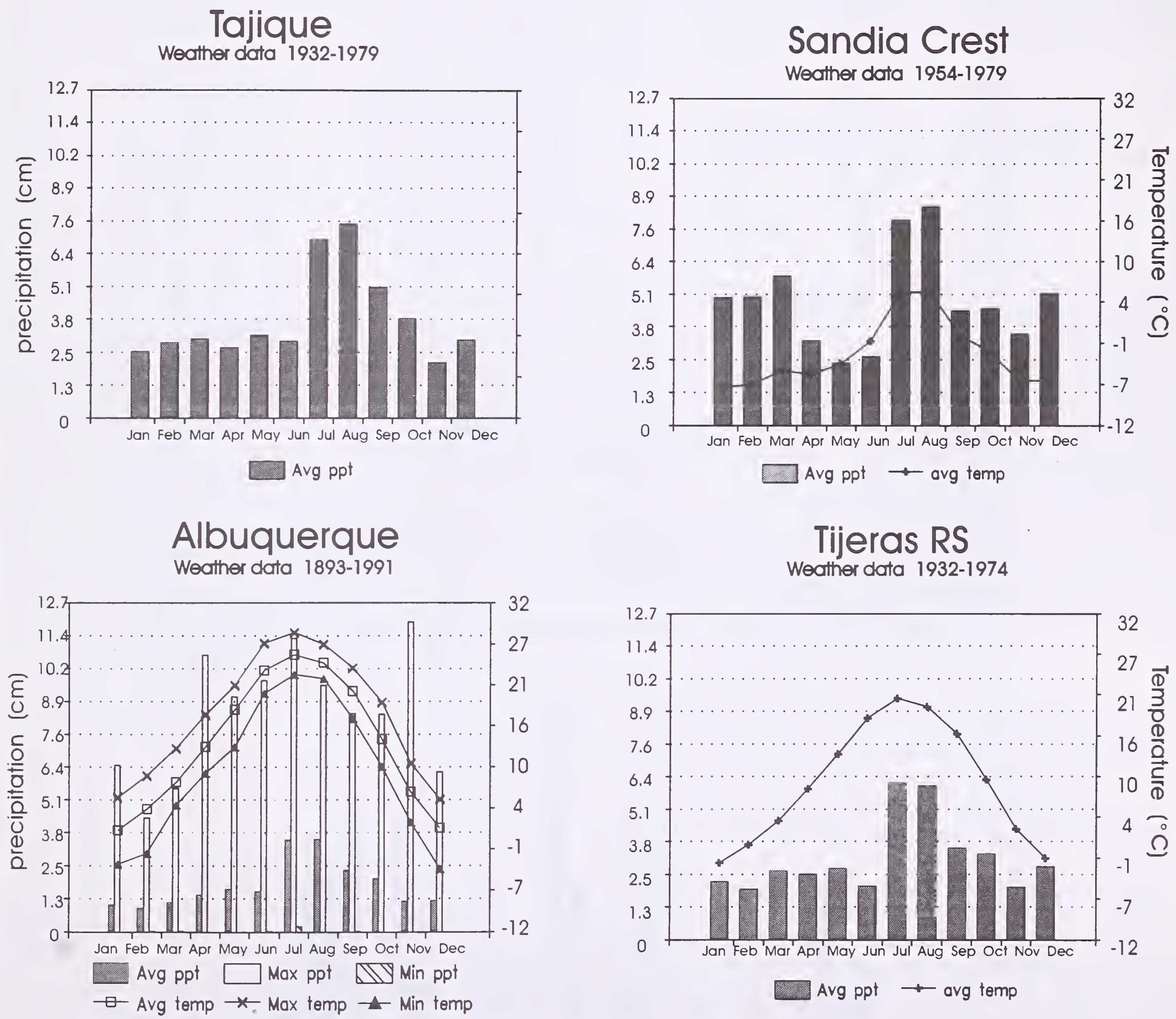


Figure 2. Monthly precipitation and temperature for several stations in central New Mexico. All stations show a strong peak in July and August. The Sandia Crest station has a secondary peak during the winter months. Data for Albuquerque include averages and extremes for 1893-1992. Note that for this station most of the monthly extreme lows for precipitation are close to zero, while some of the monthly highs are 50% or more of the annual mean of 8.3 inches. This great variability in climate from year to year is reflected in the variable growth of trees sampled for this study.

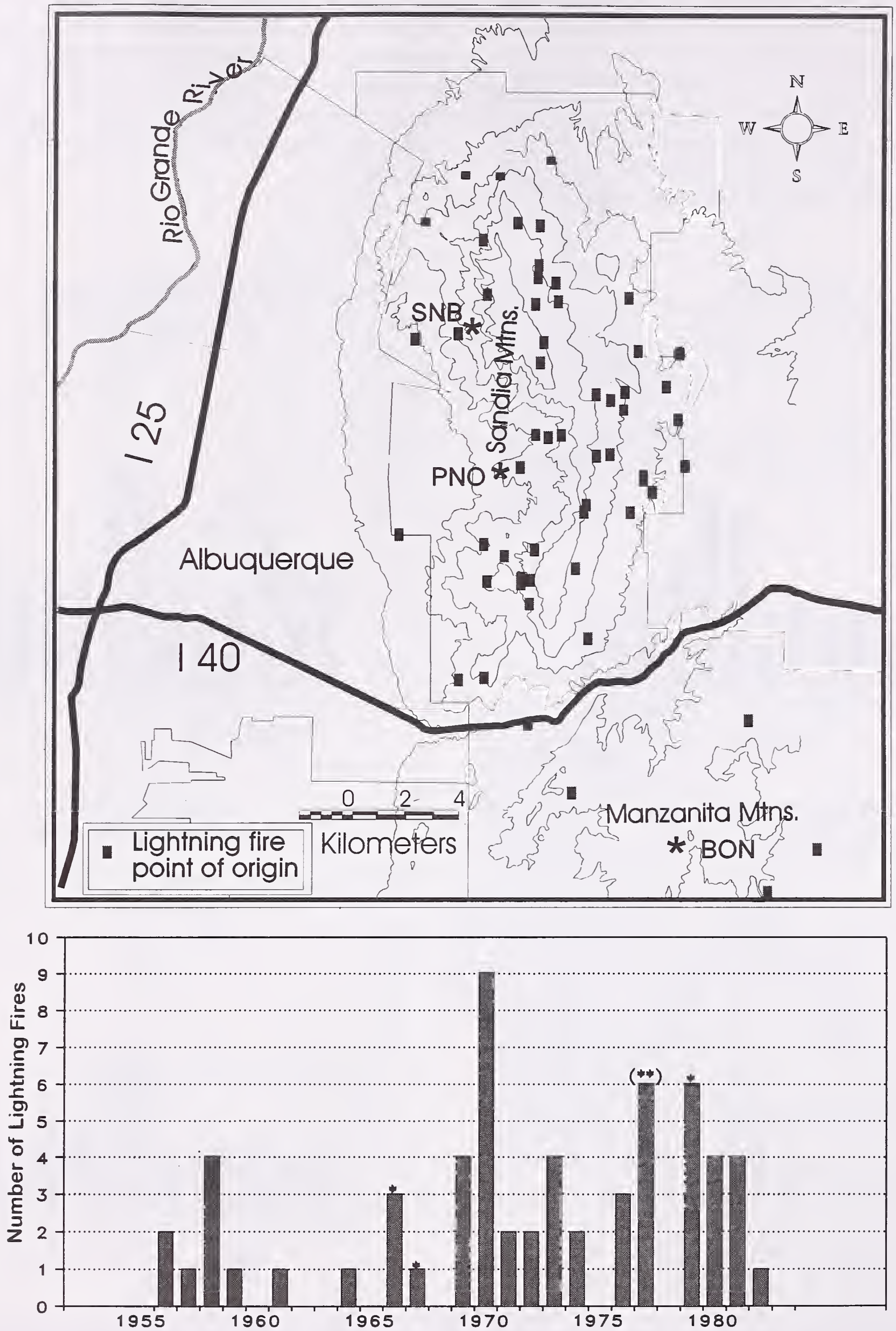


Figure 3. Thirty years of lightning-caused fire occurrences plotted on a map of the Sandia District and presented in a time series histogram. The few fires started by lightning in the vicinity of the SNB fire history site or in the Manzanita Mountains during this period are noted with an asterisk on the year of their occurrence.

Historical Background

The impact of resident human populations on local resources has varied over time as population densities, resource needs, cultural patterns, and land-use practices have changed. Early occupants relied on hunting and gathering for sustenance, and population densities were relatively low. The impact of this dispersed population with a semi-nomadic lifestyle was probably diffused over relatively large areas. The introduction of maize about 2,000 years ago and ceramic technology approximately 600 years later encouraged both a concentration and an overall increase in human population. These changes undoubtedly shifted resource utilization patterns and resulted in new environmental impacts. The exact nature and extent of land use during this period is not known, but it is probable that significant demands were placed on agricultural sites in addition to the impacts of continued hunting and gathering activities. Local-scale resource depletion has been suggested as a cause of population shifts at Chaco Canyon and other Anasazi sites of the Four Corners area during this time period (Betancourt and Van Devender 1981, Samuels and Betancourt 1982, Kohler 1988).

By the late 16th century, cultural patterns of settled, agriculturally based communities and dispersed use by scattered nomadic bands had been entrenched for nearly 1,000 years. The Spanish introduction of new species of domestic livestock, crop plants, and new technologies gradually shifted and expanded land-use impacts. In particular, the introduction of sheep, cattle, and goats resulted in intensive use of an ever-expanding area for pasturage (Wozniak 1995). This resulted both from an increase in numbers of stock and the gradual process of pasture degradation in intensively utilized areas. Adoption of sheep herding by both Navajo and Pueblo people spread the grazing impacts far beyond the reach of Spanish settlements (Denevan 1967, Bailey 1980). Pressure on land resources in the Albuquerque area was sufficient by 1750 to prompt repeated attempts by Spanish agriculturists to settle the Rio Puerco and other outlying areas in spite of the difficulties in defending remote settlements (Simmons 1982).

Increased prosperity of Spanish settlements following military successes in 1779 against the Comanches resulted in increases in livestock numbers, particularly sheep, with estimates for single landowners as high as two million head by 1800. The availability of smallpox vaccine after 1804 allowed additional population increases, again increasing pressure on area resources. However, political troubles in Spain followed by Mexican independence in 1821 had a negative impact on economic activity along the Rio Grande as resources were withdrawn from the far northern frontier. This lull lasted until the end of the American Civil War, when substantial economic resources again became available for investment in the Rio Grande valley. The arrival of the Atchison, Topeka, and Santa Fe Railway in Albuquerque in 1880 increased the tempo of expansion as it became possible for the first time to easily import and export large quantities of goods from this remote corner of the Southwest. Harvest of timber for fuel and lumber, production of wool, beef, and other agricultural products all increased with access to new markets and an expanding local population. Continued population expansion following military investments for the Second World War set the stage for the current configuration of land use in the central Rio Grande valley, which is now dominated by large urban communities (Simmons 1982).

Site and Collection Descriptions

Collection Areas

Field reconnaissance and sampling were carried out between 1992 and 1993. Areas sampled included the Sandia Crest and west face of the Sandia Mountains (Sandia District of the Cibola National Forest), the vicinity of Bonito Canyon in the Manzanita Mountains (in the Military Withdrawal Area for Kirkland Air Force Base), and the Capilla Peak area (Mountainair District of the Cibola National Forest; figure 1). Fire-scarred samples and increment cores were collected in each area. The sampling strategy targets both individual trees and stands, thus individual sites ranged from 1 to 10 hectares in size. Table 1 includes site names and descriptions of their general characteristics and the number and type of samples collected in each area.

Sandia Mountains

Collections in this area included increment cores and partial sections for determination of fire history below Sandia Crest at about 2,700 m elevation (Sandia North Bench [SNB], figure 4). Increment cores and sections were also collected between Pino and upper Bear Canyon (PNO, figure 4).

Overstory vegetation along the Crest is mixed-conifer or spruce-fir forest, with Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and limber pine (*Pinus flexilis*) occupying exposed sites. Aspen (*Populus tremuloides*) stands occur on old burns, and Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*) are found on northerly aspects and along the limestone that caps the Crest. Conditions on the red granite cliffs below are relatively xeric given the elevation, which results in excellent tree-ring sensitivity to climate as well as the extreme age of many of the trees found there.

Table 1. Site summary for fire scar and incremement core collections. Letter codes refer to the dominant overstory vegetation: SF=spruce-fir; MC=mixed conifer; PP=ponderosa pine; PJ=pinyon-juniper. Number of samples refers to the number of fire-scarred sections collected at each site. Increment cores collected are noted in the following column. Samples collected along the Sandia Crest, both increment cores and wood sections, were used for development of a tree-ring chronology for this area.

Site	Elevation range (m)	Vegetation type	Number of subsites	Number of samples	Increment cores
Sandia					
Crest	3,050-3,110	MC/SF	3	12	yes
La Luz	2,620-2,680	PP/MC	1	9	yes
Pino Canyon	2,380-2,440	PP/MC	1	2	no
East	2,620-2,680	MC	1	2	no
Manzanita					
Bonito Canyon/ Mt. Washington	2,225-2,380	PJ/PP	4	27	yes
Manzano					
Turrieta Canyon	2,500-2,680	PP/MC	2	14	yes
Capilla Peak Campground	2,680-2,800	MC	1	4	no

The SNB fire-history site occupies a west-facing bench or break that undulates along the base of the granite escarpment. It supports an open mixed-conifer forest dominated by ponderosa pine (*Pinus ponderosa*). Other tree species present include white fir, Douglas-fir, pinyon pine (*Pinus edulis*), aspen, and gambel oak (*Quercus gambelii*). Slopes are steep, though less severe than those above, and the easily eroded soil is underlain by sand and decomposed granite. Areas near the trail were badly eroded by foot traffic. A notable scarcity of fire-scarred trees characterized the site, in spite of relatively abundant evidence of fire in the form of charred wood and charcoal fragments.

Manzanita Mountains; Military Withdrawal Area (MWA)

Collections were obtained in the Manzanita Mountains to the east of Mt. Washington (figure 4). Topographically, the area consists of sedimentary mesas dissected by north-south oriented drainages. Elevations range from 2,000 m to 2,600 m at the Manzano Lookout. Soils are derived from sedimentary substrates, either limestones or sandstones, and vary from thin on south-facing slopes and outcrops to thick alluvial deposits along drainages. Overstory vegetation in these collection areas is pinyon-juniper (*Pinus edulis-Juniperus scopulorum*) forest with stringers and pockets of ponderosa pine occupying north aspects and drainages. The pinyon-juniper forest forms dense stands on all aspects and substrates. There is a well-developed canopy and generally abundant reproduction, particularly of pinyon. Gambel oak clones are present in most pinyon-juniper stands. Ponderosa pine stands were generally characterized by thickets of reproduction over-topped by widely spaced, uneven-aged pines and junipers. Gambel oak is common in clonal clumps and thickets in these stands as well.

An open grassy swale occupies the upper portion of the Bonito Canyon drainage; however, natural openings are rare. Many large ponderosa pine logs were observed in the pine stands lining this canyon. Additionally, all areas sampled showed evidence of extensive harvest of juniper of all sizes and more limited cutting of pole-sized pinyon and ponderosa pine. Nearly all these trees had been axe-harvested and the stumps were weathered, indicating that they had been cut long ago. A few timber-sized ponderosa pine were also harvested some time in the past. In addition to the fire-scarred sections, some of these stumps with well-preserved sapwood were sampled to provide information on the land-use history of the area.

Twenty-seven fire-scarred cross sections were collected in four sub-areas along Bonito Canyon and near the old Manzano lookout on Mount Washington (figure 4, table 1). Increment cores were collected in these areas from both ponderosa pine and pinyon pine in order to develop tree-ring chronologies for climatic reconstruction and to evaluate the approximate age structure of the forest. The Bonito Canyon (BON) collection area has a corridor of well-developed ponderosa pine forest along the drainage. The Manzano Lookout (MLO) collection area is a pinyon-juniper forest with scattered pockets of ponderosa. Thin rocky soil covers the limestone substrate. The Manzano Lookout Road (MLR) site is located along the road between David and Bonito canyons, in pinyon-juniper forest

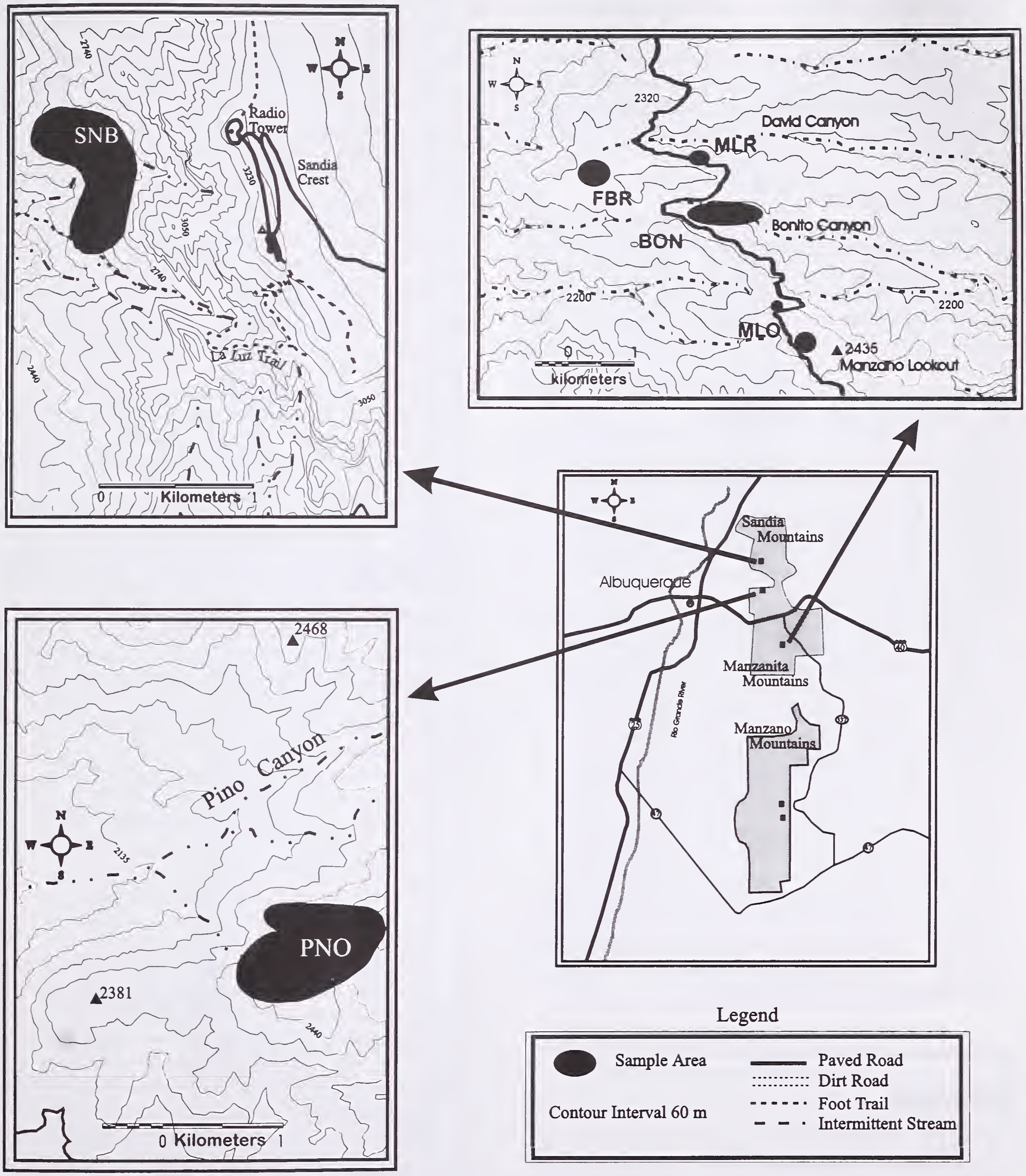


Figure 4. Location of the collection areas in the Sandia and Manzanita Mountains.

with scattered ponderosa. Soils appear thin outside of the grassy portions of the drainage bottom, and the substrate is limestone. The Fuel-Break Ridge (FBR) collection area is similar to the MLO area with the exception that a sandstone cap covers the limestone in this area and provides the substrate for soil formation. Soils here are thin as well. The area was mechanically thinned several years ago and the slash piled and burned, leaving an open stand with grassy understory.

Manzano Mountains

Collections were obtained in three areas on the Mountainair District between Capilla Peak and the New Water Campground (figure 5). Fire-scarred sections were collected east of Capilla Peak campground, and increment cores were collected west of the access road about 1 km south of Capilla Peak. Fire-scarred sections and increment cores were collected at the head of Canyon de Turrieta. These sites are farther from early Spanish settlements than those previously discussed, although settlements and a mission were established at the southeastern foot of the mountains in the 17th century. These areas were abandoned before the 1680 Revolt and were not resettled until the 19th century. Use during the 18th century was mainly confined to the western foothills and adjacent grasslands, and consisted of seasonal grazing, particularly in the winter when conditions to the north were more severe (Simmons 1982).

Fire-scarred sections were collected in the vicinity of Capilla Peak Campground between 2,740 and 2,800 m elevation. This area supports a mixed-conifer forest with Douglas-fir, southwestern white pine (*Pinus strobiformis*), ponderosa pine, and gambel oak dominating the overstory. Soils are thin to moderately deep here, underlain by limestones and metamorphic bedrock. Canyon de Turrieta is on a south-facing slope between 2,520 and 2,700 m elevation and supports an overstory dominated by ponderosa pine with scattered Douglas-fir, southwestern white pine, and pinyon pine. The stand was located on steep slopes with thin soils and numerous outcrops of metamorphic rock, and was quite open, with a grassy understory. Ponderosa pines and Douglas-firs were cored here to develop a local tree-ring chronology as a cross-dating standard. Fourteen fire-scarred sections were collected around the head of Turrieta Canyon.

Methods

Selected sites were surveyed for fire-scarred trees. Trees exhibiting well-preserved, multiple fire scars were flagged for subsequent collection. Complete cross sections were collected from logs and stumps, while partial or "wedge" sections were removed from live trees and snags with a chain saw. Snags were occasionally felled for reasons of safety. Sampling in the Sandia Wilderness was accomplished with hand saws and increment borers. Field notes describe sample characteristics, location, and topographic position. Samples were returned to the laboratory, where they were sectioned with a band saw and surfaced with power belt sanders to a polish that allowed clear viewing of annual rings and cellular structure with a 30x binocular microscope. Samples were then cross dated. All annual rings were assigned to the calendar year of formation using the dendrochronological technique of crossdating or pattern matching (Glock 1933, Douglass 1941, Baillie 1982, Fritts and Swetnam 1989). Crossdating allows precise determination of the years in which fire injuries occur and reliable cross comparison of fire dates among samples and between sites.

Increment cores from selected trees were crossdated and ring widths were measured for development of tree-ring index chronologies. Comparisons with climatic data from New Mexico climate divisions 8 (central Rio Grande Valley) and 6 (eastern plains), as well as records from several individual stations, were used to determine the correlation of ring width variation of these chronologies with local climate. The tree-ring chronology developed from the Bonito Canyon site was used as a proxy for annual rainfall to assess potential relationships between fire occurrence and climatic factors (figure 6). Assessment was accomplished by comparison of fire dates with the rainfall proxy through the use of superposed epoch analysis (Baisan and Swetnam 1990, Swetnam 1993, Swetnam and Baisan 1996). Statistics used to compare fire regimes (means, standard deviations, fire intervals, etc.) were derived from runs of the FHX2 software package developed by H. D. Grissino Mayer (Grissino-Mayer 1995). Significance levels used in table 2 are from a t-test of differences between the normalized mean fire interval distributions performed by this program.

Although fire histories developed from these data represent point samples in space, general synchrony of fire dates between trees and stands, or lack thereof, is an indication of relative area burned in a given year. Furthermore, the degree of synchrony in fire dates provides important information regarding the spatial homogeneity or heterogeneity of the fire regime for a site. Previous research has shown a link between fire frequency and spatial character, with higher fire frequencies resulting in more heterogeneous burn patterns (Swetnam 1993). For more detailed descriptions of fire history methodology and analytical procedures, see Dieterich and Swetnam (1984), Grissino-Mayer (1995), and Swetnam and Baisan (1996).

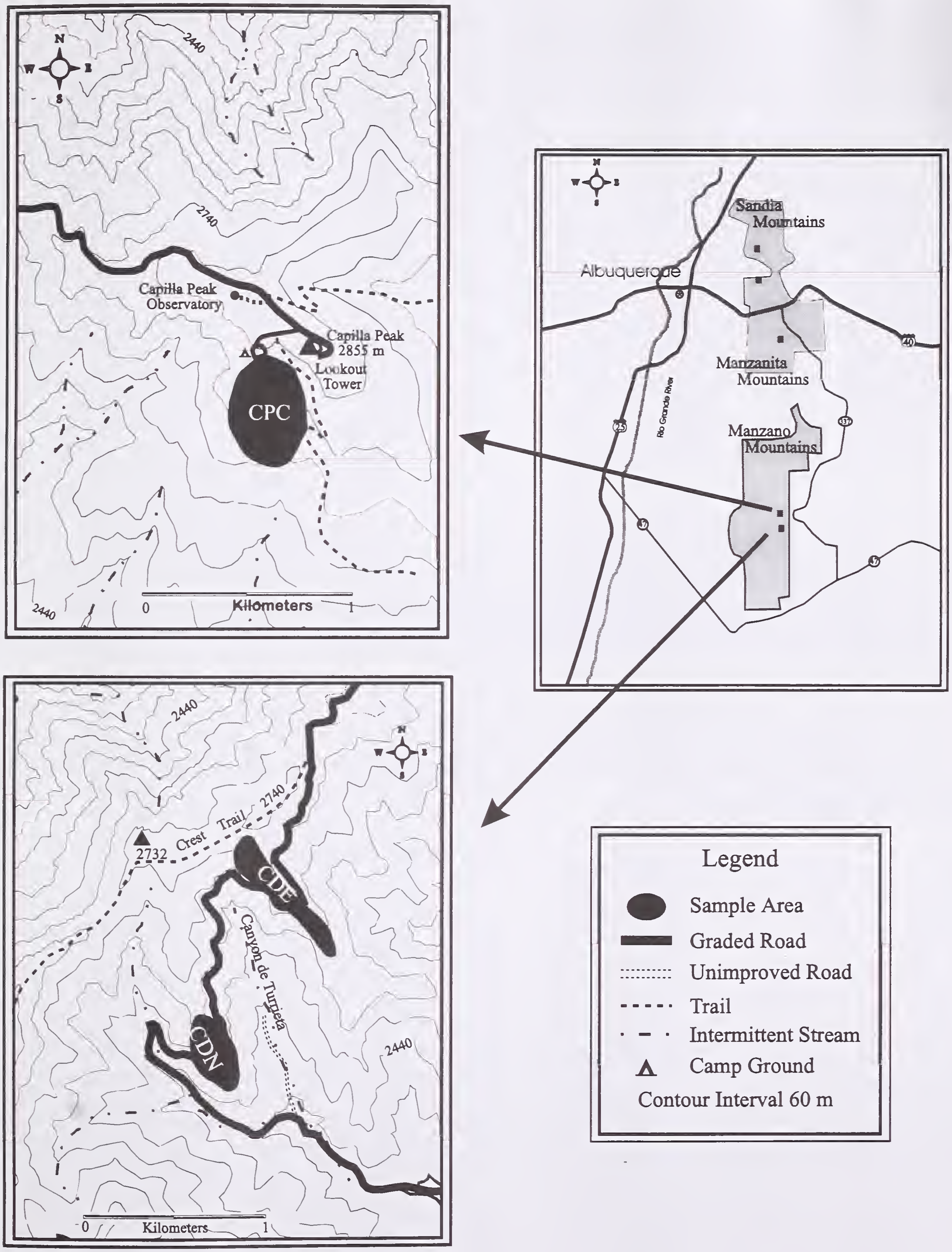


Figure 5. Collection areas in the Manzano Mountains.

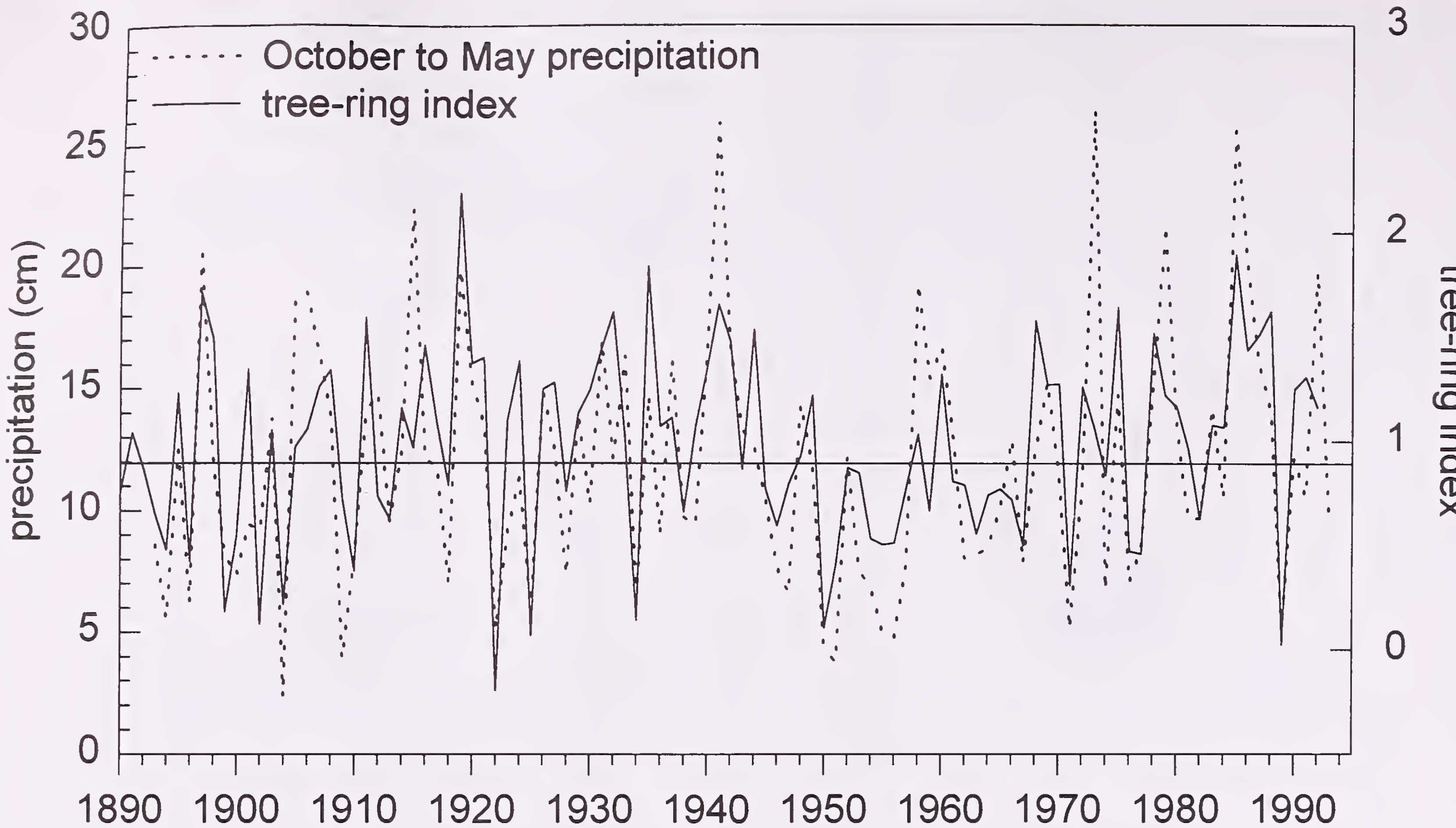


Figure 6. Climate/tree-growth relationships for Bonito Canyon ponderosa pine tree-ring series developed for this project. Cool-season precipitation (October to May) relates positively to tree growth. The simple correlation of tree-ring width and precipitation was 0.7.

Results and Discussion

The three collection areas represent a proximity-to-humans and land-use intensity gradient, running from north to south from the population centers along the Rio Grande, west of the Sandias to the relatively more remote sites on the east face of the Manzano Mountains. This gradient allows for a comparison of the relative intensity and timing of land-use impacts on the fire regimes in the three areas. In addition to this spatial gradient, the temporal dimension of the reconstruction spans a series of cultural and political changes, from the arrival of the Spaniards in the 16th century to the acquisition and development of the New Mexico territory by the Americans in the 19th and 20th centuries. For the purposes of analysis, the fire-history reconstructions were divided into four periods based on changes in fire frequency and cultural context as follows: period I—before the Pueblo revolt of 1680; period II—Spanish recolonization and expansion (1681-1784); period III—the period of quiescence (1785-1820) followed by political transitions (1821-1905); period IV—contemporary forest management and fire suppression (1906-1992).

Manzanita Mountains

Compilation of the fire-scar dates derived from the scarred sections reveals a history of fire occurrence that varied considerably through time and space (figure 7c). Period I was characterized by moderately frequent to frequent fire occurrence. Many fires during this period injured either a single sampled tree or only a few trees, though at least some fires appear to have spread over a significant portion of the entire area sampled, as indicated by synchronous fire dates among many of the trees. This suggests a fire regime generally characterized by patchy fires of relatively low intensity, burning in an area where fuels were spatially heterogeneous. Only occasionally were fuel and weather conditions conducive to widespread fires intense enough to scar many trees. The mean fire interval (MFI) for this period was 6 years (table 2a). The fire record was compared with an estimate of past climate derived from tree rings to test for associations. The com-

parison showed that fires typically occurred during dry years (figure 8a).

Following the Pueblo Revolt of 1680, period II (1681-1784) was characterized by widespread fires that scarred trees over most of the area sampled. The period began with little fire activity until a fire in 1723, and ended following a widespread fire in 1773. The MFI was 11.2 years, nearly double that of the previous period. The fire recorded in 1748 occurred during a year in which more than two-thirds of all fire chronologies developed for the Southwest recorded a fire (Swetnam and Baisan 1996). Spanish documents for this region refer to 1748 as a year too dry for travel (Bailey 1980). Interestingly, 1746 and 1747 were extremely wet, as indicated by tree-ring based climate reconstructions (Fritts 1991). Such conditions are most favorable for widespread fires in semi-arid climates, since the wet years limit fire activity and encourage fine fuel production, providing a more homogeneous fuel matrix that spreads fire effectively when weather conditions favor burning. The wet-dry pattern characterized the fire-climate relationship during this period, with the second year before the fire year (lag -2 in figure 8a) typically wetter than average and the fire year itself drier than average.

The transition from period II to period III was distinguished by the absence of fire at any site for 38 years, and for 48 years in the BON sub-area. The sample from the MLO site showed no direct evidence of any fire after 1763; however, an axe-cut stump sampled here was injured in 1842, perhaps by the fire that occurred that year. Spreading fires returned first to the FBR site in 1811, to the BON site in 1821, and then to all sites in 1842. Following the fire in 1842, fire activity diminished at all sites and ceased completely after 1904. The fire of 1842 must have been particularly intense, because most of the sampled trees were scarred by it. Roots sampled in a cut-bank were killed on this date, suggesting severe soil heating in some areas. Probably the preceding two decades without fire allowed an increased fuel load to develop over the entire area, increasing fire intensity. The MFI for this period shifted back toward that of period I, with a value of 7.8 years (table 2a).

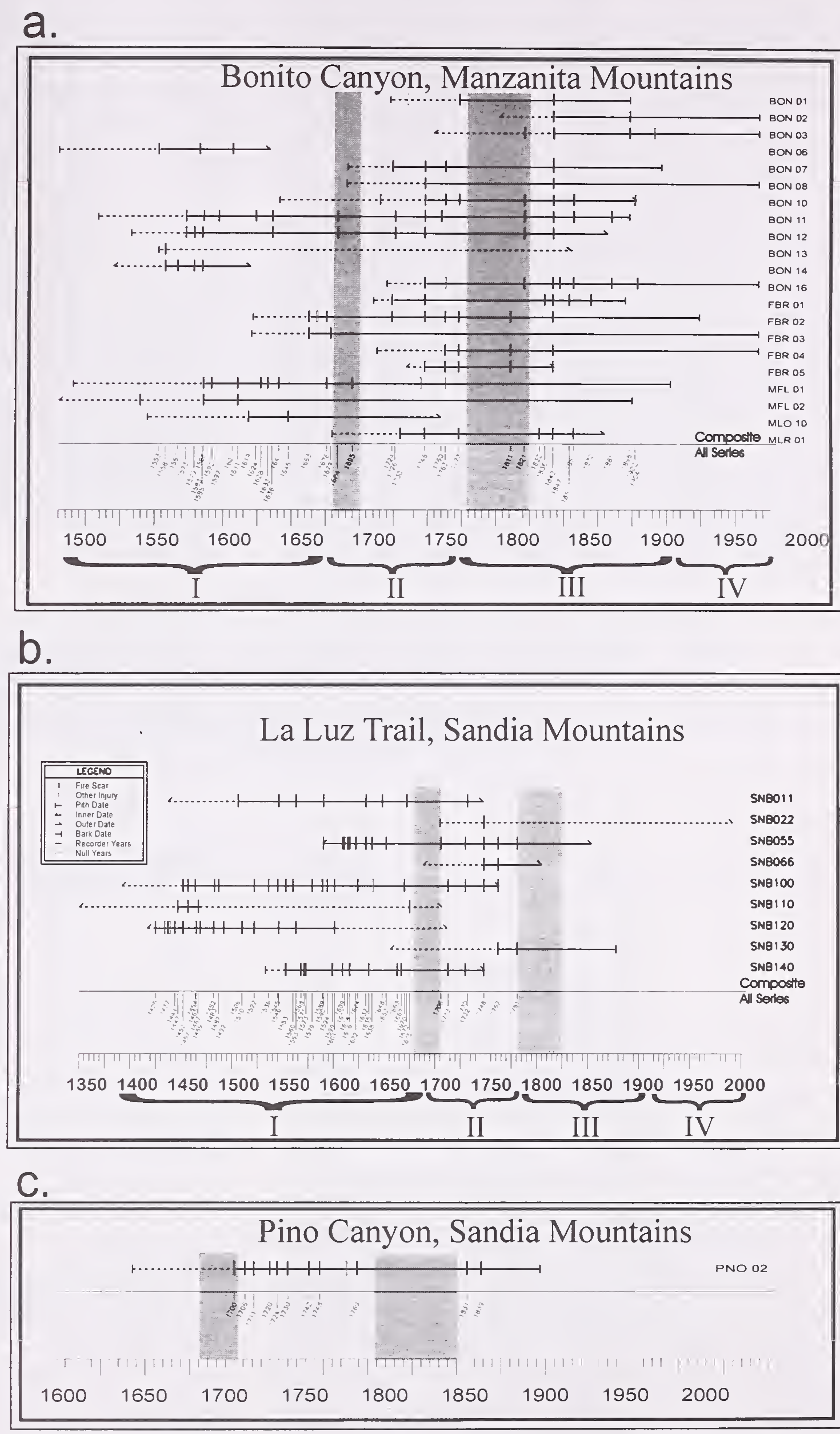
Table 2a. Mean fire intervals (MFI) for four collection areas by time period. Note the lack of fire in period III at La Luz and for all sites in period IV, as well as the shifts in MFI between periods I, II, and III. The means for periods I and II at the La Luz site were statistically distinguishable at the 95% level. See table 2b for MFI statistical summary.

	MFI (years)			
Site	**Period I (1550-1680)**	**Period II (1681-1784)**	**Period III (1785-1905)**	**Period IV (1906-1992)**
Sandia/La Luz	4.5*	12.5*	∞	∞
Manzanita Mountains/ Bonito Canyon	6.0	11.2	7.8	∞
Manzano Mountains/ Turrieta Canyon	—	7.17	6.0	∞
Manzano Mountains/ Capilla Peak	—	—	7.4	∞

Table 2b. Stastical summary for the Mean Fire Intervals (MFIs) by period. Summary statistics include: number of intervals (n); coefficient of variation (CV); and standard deviation (SD).

	Period I			Period II			Period III			Period IV		
Site	**n**	**CV**	**SD**	**n**	**CD**	**SD**	**n**	**CV**	**SD**	**n**	**CV**	**SD**
La Luz	27	0.62	2.8	6	0.53	6.6	0	—	—	0	—	—
Bonito	21	0.57	3.4	8	0.81	9.0	12	0.57	4.5	0	—	—
Turrieta	—	—	—	12	0.90	6.5	20	0.74	4.5	0	—	—
Capilla	—	—	—	—	—	—	15	0.90	6.6	0	—	—

Figure 7a, b, and c. Master fire chronology charts for the Manzanita(a) and the Sandia Mountains (b, c). Horizontal lines represent the time spans of individual specimens while vertical bars represent the dates of fire scars or other injuries recorded on the sample. Sample numbers are printed to the right. The dotted portion of each line represents the time before the first clear fire injury, after which the tree is more susceptible to re-scarring. Space is represented on the vertical axis as each sample represents a point and samples are arranged roughly in order of their actual distribution on the landscape. Widespread fires can be noted by the vertical alignment of bars. The gray bars represent fire-free or reduced fire periods at the SNB and BON sites associated with the Pueblo Revolt and the Comanche peace.



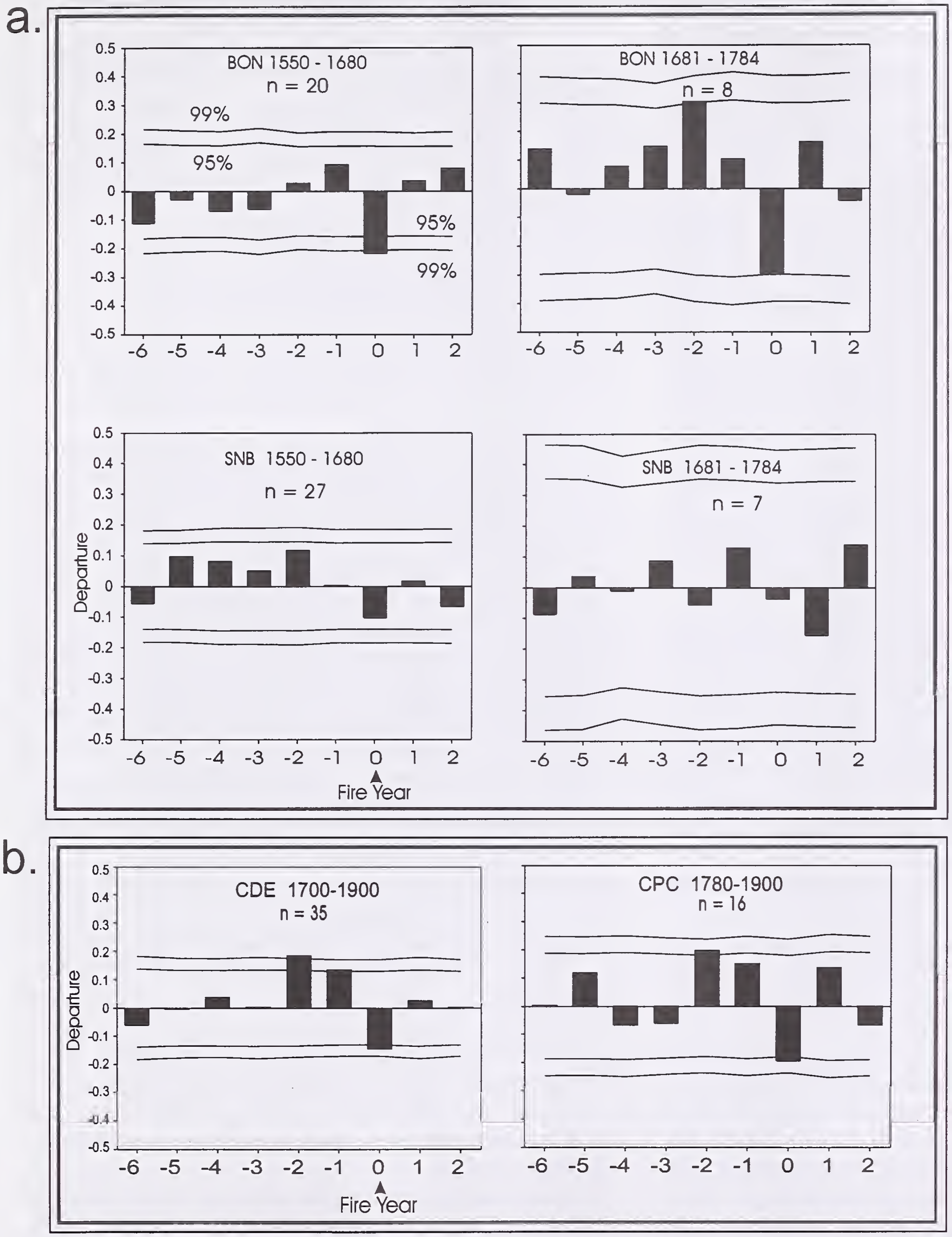


Figure 8 a, b—Plots of superposed epoch analysis comparing estimates of past climate with fire occurrence for periods I and II at the northern fire-history sites (a) and the Manzano Mountain sites (b). The X axis represents a set of nine years, from six years before a fire event to two years following it. Values are averaged at each of these positions for all fire years within the time period analyzed. Confidence intervals are provided by picking a set of dates at random in a thousand simulations. The spread of the confidence bands is greatly affected by the number of events in the simulation (n) that is determined by the actual number which occurred. The data from the Manzanita Mountains show a consistent relationship between drought and fire occurrence, while the La Luz/SNB site shows no relationship between fire and climate during any period. Note the general relationship of fire occurrence on a dry year preceded by one or two wet years at the Manzano sites (CDE and CPC). This pattern is typical of semi-arid forested sites with an open stand structure.

Period IV, commonly referred to as the fire suppression era, was characterized by the absence of spreading fire at all sites. The relative lack of fire during this period is typical of most forest and woodland areas studied in the southwestern United States (Swetnam and Baisan 1996).

A reasonable explanation for these changes in fire regime can be found in the cultural-political context of each time period. In the centuries before the Pueblo Revolt of 1680, citizens of nearby pueblos and nomadic hunters and gatherers undoubtedly used this area. Users who set fires before 1680 may have increased the fire frequency during the early period. Modern fire records show infrequent, scattered lightning ignitions in this area, with an annual average of 0.3 per year. It is difficult to reconcile the high fire frequency during this period with such a low rate of ignition; however, changes in vegetation and forest structure over subsequent centuries may have led to changes in the rate of ignition. Changes in climate regime could lead to changes in both fuels and ignition rates. Regardless of their source, fires were clearly frequent in this area before 1680.

Spanish settlements in the Rio Grande valley grazed large flocks of sheep and goats on the surrounding grasslands, and this use intensified and spread throughout the 18th century (Wozniak 1995). The town of Albuquerque was established in 1706 by incorporating the residents of an area resettled following the Pueblo Revolt. By the mid-1700s, population growth here was forcing the migration of families into outlying areas and undoubtedly increasing the impact on the surrounding natural resources (Simmons 1982). Toward the latter half of the century, significant numbers of sheep were being exported to Chihuahua. By 1800, the trade in sheep to the south was at a peak, and the governor of Santa Fe alone was said to have 2,000,000 head tended by 2,700 shepherds (cf. Charles 1940). Since intensive grazing can essentially eliminate fine herbaceous fuel in an area, it is not unreasonable to assume that the drop in fire frequency after the turn of the 19th century and the hiatus in fire occurrence between 1773 and 1811 were due to heavy grazing. Grazing has been suggested as a cause for early declines in fire frequency in other areas of the Southwest (Savage and Swetnam 1990, Touchan et. al. 1995, Swetnam and Baisan 1996). The shift that occurred at the beginning of this period from a fire regime characterized by frequent, patchy fires to one dominated by sweeping fires at longer intervals suggests changes in fuels, climate, and/or ignition sources and frequency. Such changes, in turn, must have significantly altered the fuel and vegetation complex.

Political conditions in New Spain deteriorated after 1800, cumulating in revolution and independence for Mexico in 1821. Policies of appeasement directed toward the nomadic Apaches and Comanches were abandoned during this time, and the northern frontier was left to fend for itself both militarily and economically. A period of contraction and intensified warfare with the Indians commenced that was not stemmed until the latter part of the century (Simmons 1982). Abandonment of outlying areas that had become unsafe for pastoral pursuits probably resulted in a regrowth of herbaceous fuels and the return of fire to these areas. Following the ceding of Arizona and New Mexico Territories to the United Sates in 1848, economic conditions gradually began to improve. Livestock grazing once again increased, resulting in the decline in fire activity seen after the mid-1800s. An axe blaze on a tree in Bonito Canyon, perhaps marking a trail, was dated to 1855 or 1856, indicating use during this period.

Table 3. Cutting dates for the Bonito Canyon and Mt. Washington area, Manzanita Mountains. The ++ indicates that this tree was cut an undetermined number of years after the date given.

Date	Description
1855/6	Axe-cut blaze on a ponderosa pine in Bonito Canyon
1866++	Pole-sized ponderosa pine stump, outside eroded, last rings missing
1894	Pole-sized ponderosa pine stump
1894	Timber-sized ponderosa pine stump
1895/6	Axe wound on juniper
1898	Pole-sized ponderosa pine stump
1900+/-	Juniper stump
1921	Juniper stump

Fire suppression became national policy around the turn of the 20th century. Livestock grazing probably peaked in New Mexico during the early 1900s (Denevan 1967) and has continued at variable levels since that time. Widespread fires, as recorded by fire scars, were absent during this period. Harvest dates for the stumps range from 1895 to 1921; most dates are prior to 1900 (table 3). Historic photos show large wagon loads of firewood being hauled through a desolate-looking Tijeras Canyon to Albuquerque in the 1920s (Cordell 1980). One of the harvest dates, 1898, coincides with a fire-scar date, providing circumstantial evidence of human ignition, particularly since this year was relatively wet and less likely to have sustained widespread fires.

A head-cutting arroyo in the alluvium below a dirt tank in Bonito Canyon was probably initiated in the 1910s, based on the death dates of exposed roots that we sampled in the cut. The 1890-1910 period was generally dry in this area, while the teens were relatively wet (Fritts 1991). Such juxtaposition of dry and wet periods may lead to erosive episodes. Additionally, the area was probably heavily grazed and undoubtedly roaded for fuelwood harvest about this time. Perhaps the dirt tank was constructed to limit the extension of the arroyo.

Sandia Mountains

La Luz Area

Although an initial search suggested that fire-scarred material was not abundant in the areas selected, nine fire-scarred sections were eventually located and collected during two field trips. Many of the samples proved to be very old, with the earliest rings dating from the 1300s and 1400s. The earliest fire date recorded was 1425 and the latest was 1781. The intervening period was characterized by episodic fire occurrence with pronounced variation in frequency and spatial character through time. The outermost ring dates of several samples, including two in-situ stumps, fell in the early 18th century, while a fire-scarred snag with complete sapwood and bark indicated the last fire at this site had occurred in 1781. This evidence suggests that widespread fires have been absent in this area for more than 200 years. Had fires continued to occur here, this remnant material might have been consumed, and fresh scars would have been created on surviving trees.

As in the case of the MWA, we have divided the fire history into periods based on fire frequency, spatial character, and cultural context (figure 7, tables 2a and b). An initial phase begins with the first fire scar in 1425 and ends about 1680. Fires during this period were frequent (MFI=4.5 years calculated for 1550-1680), but each fire scarred few trees. This result was unexpected, as the sampled area was relatively small and occupied a continuous slope that would encourage fires to spread over the area. The asynchrony of fire dates suggests that fuel was unevenly distributed, perhaps as a result of the high frequency of burning. Period I was followed by a gap of 31 years during which no fires were recorded (1675-1706). The first fire during period II occurred in 1706, and fires continued sporadically until 1781, after which no more fires were recorded by any sampled tree. The fire regime during this period was remarkably different from the first, with longer intervals between fires, yet with each fire typically scarring most of the trees in the area. Longer fire intervals would have resulted in greater fuel accumulation between fires and thus higher fire intensity and more homogeneous spread.

The third phase (corresponding to periods III and IV at the Manzanita site) continues to the present, with no evidence of fire occurring in the area for more than 200 years. This early cessation of fire probably explains the lack of living fire-scarred trees in this area. It is also possible that all fire wounds had healed over on the living trees; we sampled dead material with the single exception in which a buried scar was noted on a live tree and was sampled with an increment borer.

The first period, with frequent, patchy fires, appears to have a higher fire frequency than would be expected from natural ignition sources alone. Modern lightning fire data show an annual average of only two fires per year for the entire mountain range, while fire starts in the vicinity of the collection area are very rare. Only three years out of 30 had lightning ignitions in this area, and during one of those years the fires started north of North Sandia Peak, several kilometers away from this site (figure 3). This rate of ignition could not produce an MFI of 4.5 years, while even an MFI of 10 years would require that all ignitions in the vicinity be successful in spreading to this site. It is possible that American Indian populations in this area started fires for resource manipulation, perhaps for hunting, improving browse for game species, or for some other reason. Land use practices of the local population for this period are poorly known; however, use of fire to manipulate highly valued resources is well-documented in other areas of North America (Lewis 1973).

Additionally, fire occurrence during this period shows no consistent relationship with climate (figure 8a). Most fire history reconstructions exhibit a relationship with current and/or prior year's climatic conditions (Swetnam and Betancourt 1990, Baisan and Swetnam 1990, Touchan et al. 1995, Swetnam and Baisan 1996, Grissino-Mayer et al. 1994). The lack of fire-climate association in this area also suggests that humans had a role in setting some of these fires. It is possible that fires originating elsewhere spread long distances to this site, that fuel relationships were different in the past, or that lightning ignition rates varied dramatically through time. However, these hypotheses fail to explain why this area exhibited such dramatic differences from most other areas studied in the Southwest.

The last fires during period I occurred just before the Pueblo Revolt of 1680, followed by a period of three decades without evidence of fire. The retreating Spaniards burned Sandia, Alameda, and Isleta Pueblos in August 1680, and again the next year on a short-lived punitive expedition (Simmons 1982). The area was largely abandoned until 1692-1695, when resettlement by Spanish colonists began. By 1706, the population of the area had increased sufficiently to justify the official acknowledgment of Albuquerque as a town. Perhaps the lack of fire during this period reflects the cultural changes that took place at this time. The previous initiators of fire had departed and some time was necessary for fuel continuity to develop sufficiently for fire to spread to this area from elsewhere.

During the second period (1706-1781), this site supported a distinctly different fire regime, with fires occurring at longer intervals and most of the trees scarred by each event. Such a regime could have been produced by relatively infrequent fires which swept up slope from below, perhaps originating in the grasslands and foothills at the base of the mountains. The fire intervals were more consistent with modern lightning fire data, which show

scattered ignitions along the west face at irregular intervals. This period may reflect the natural dynamics of fuel accumulation, ignition, and fire spread in a relatively unmanipulated landscape. However, fire occurrence during this period also exhibits no relationship with climate, again suggesting that humans may have been involved in setting some of these fires. The hypothesis that the primary source areas of fire during this period were the grasslands and foothills suggests that ignitions from lightning strikes along the face of the mountains were quite rare, or at least did not spread well across the rugged terrain. Modern fire data support this hypothesis, in part, documenting few ignitions along the west face of the mountains north of Pino Canyon, although the grassy *bajada* (piedmont or erosion slope) is now occupied by the suburbs of Albuquerque and data are not available on the ignition rate there before urbanization.

In 1779, a military campaign by the Spanish governor of the province succeeded in defeating the Comanches, who had been raiding settlements and driving off large numbers of livestock. By the later portion of the 18th century, the local population had expanded and livestock, particularly sheep and goats, were probably being grazed in sufficient numbers to effectively eliminate the fuels necessary to carry fire in the lower country. The fire-scar record suggests that continued grazing of stock into the current century completely eliminated fire from this area. It seems unlikely that the impact of grazing extended to the site itself and directly affected fuel continuity here over the entire 200-year period. Rather, the area was cut off from all previous sources of fire and thus isolated by the reduction in continuity of fuels below.

An additional observation, perhaps indicative of change at this site, derives from the characteristics of tree growth of the samples collected here. The earliest portions of many samples (i.e., 1400-1700 AD) show relatively little year-to-year variability in ring-width, suggesting that environmental factors rarely limited the tree growth during this period. Trees currently growing in this area show high year-to-year variability in ring-width, indicating extreme sensitivity of growth to environmental conditions, particularly moisture availability. This pattern suggests that some type of change occurred, either in the climate or in site characteristics. The climate change hypothesis seems unlikely, as trees growing on the Sandia Crest 800 m upslope exhibit no such change in growth patterns. A possible explanation is that site degradation, perhaps due to a period of overgrazing and subsequent erosion, might have affected the water-holding capacity of the soil and resulted in increased moisture stress on the vegetation.

Pino Canyon

Stumps of pole-sized and larger trees were found scattered throughout the area, indicating extensive utilization of timber from this watershed. A single fire-scarred, axe-cut stump was sampled on a ridge that divides Pino Canyon from Embudo Canyon to the south. This specimen yielded 12 fire dates, the first in 1700 and the last in 1839. This 70 cm diameter tree was felled in 1872. The two fire dates in the 19th century suggest that fires continued to occur in this area for some time after their cessation at the SNB site along the La Luz trail to the north. The forest overstory in this area is dominated by ponderosa pine and gambel oak. This site may have had more local ignitions than SNB, or greater fuel continuity generated by the pine canopy. Modern lightning fire data document a consistent pattern of ignitions in this watershed (figure 3). Although only a single sample was collected here, it is noteworthy that the two 19th century fires it recorded followed a 62-year gap (1769-1831; figure 7b) that coincides with a period of limited or no fire activity in our other sites. These fires occurred during a period of economic contraction, when grazing pressure was perhaps less than before or after this period. Additional fire-scar collections in the ponderosa pine stands in upper Bear, Embudito, and Embudo Canyons might serve to better define the variability of fire regime and cultural influences across the west face of these mountains.

Manzano Mountains South

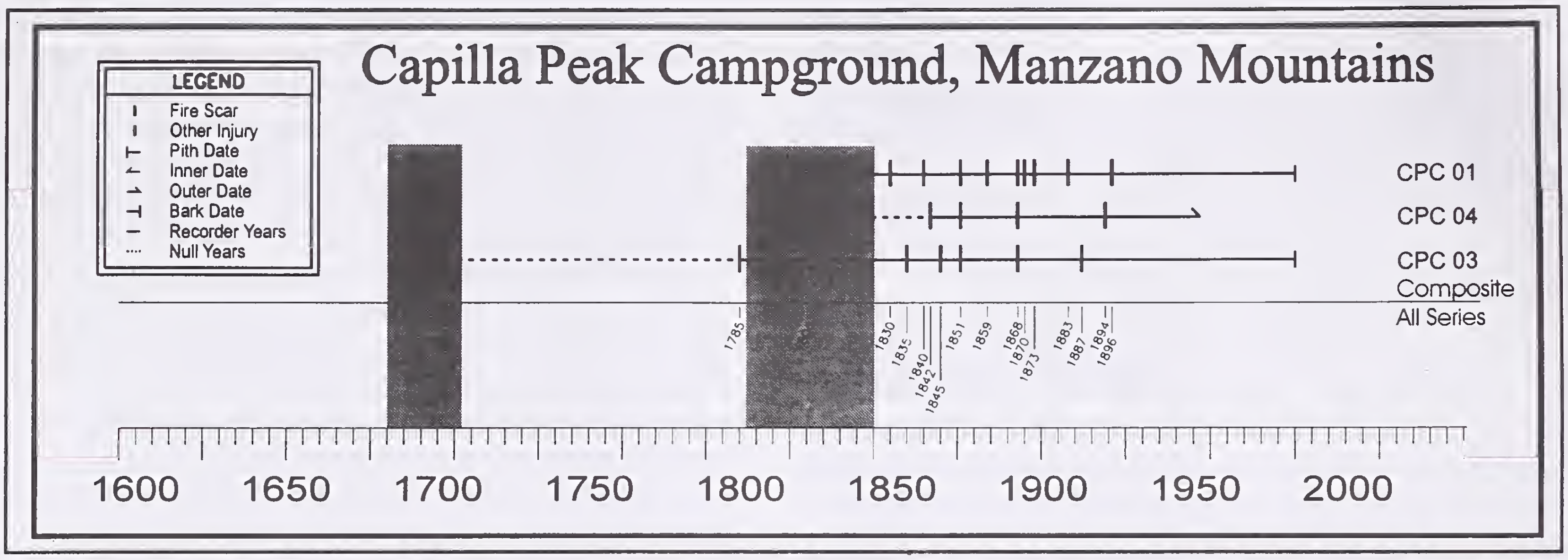
Capilla Peak

The forest in the sampled area is fairly open, with an understory of grasses and shrubs. A section collected from a Douglas-fir snag at this site, the oldest specimen collected in the Manzanos, had a pith ring date of 1334. Fire-scarred specimens from this site recorded surface fires at moderate intervals from the late 18th century through the 19th century (figure 9a). The MFI for this site was 7.4 years (table 2a). Many of the fire dates match those at the Canyon de Turrieta site, and since fires could have spread between these areas, these synchronous dates suggest that large areas burned during some years. The last fire date recorded in this area was 1896. The fire regime here appears to have remained largely undisturbed until the establishment of the forest reserve system early in the 20th century.

Canyon de Turrieta

The fire history developed for this site showed evidence of surface fires from the early 1600s; however, few of the sampled trees had a consistent record before a fire in 1785 (figure 9b). A fire in this year scarred most of the specimens, and subsequently they recorded frequent surface fires over the next century, with an MFI of 6 years (table 2a). The last consistently recorded fire occurred in 1899, although a single tree recorded a fire in about 1905. The fire record for this site lacked sufficient data before 1785 to reliably interpret changes in fire frequency and spatial patterns. This paucity of fire between 1785 and 1806, and the relatively frequent occurrence of fires during the 19th

a.



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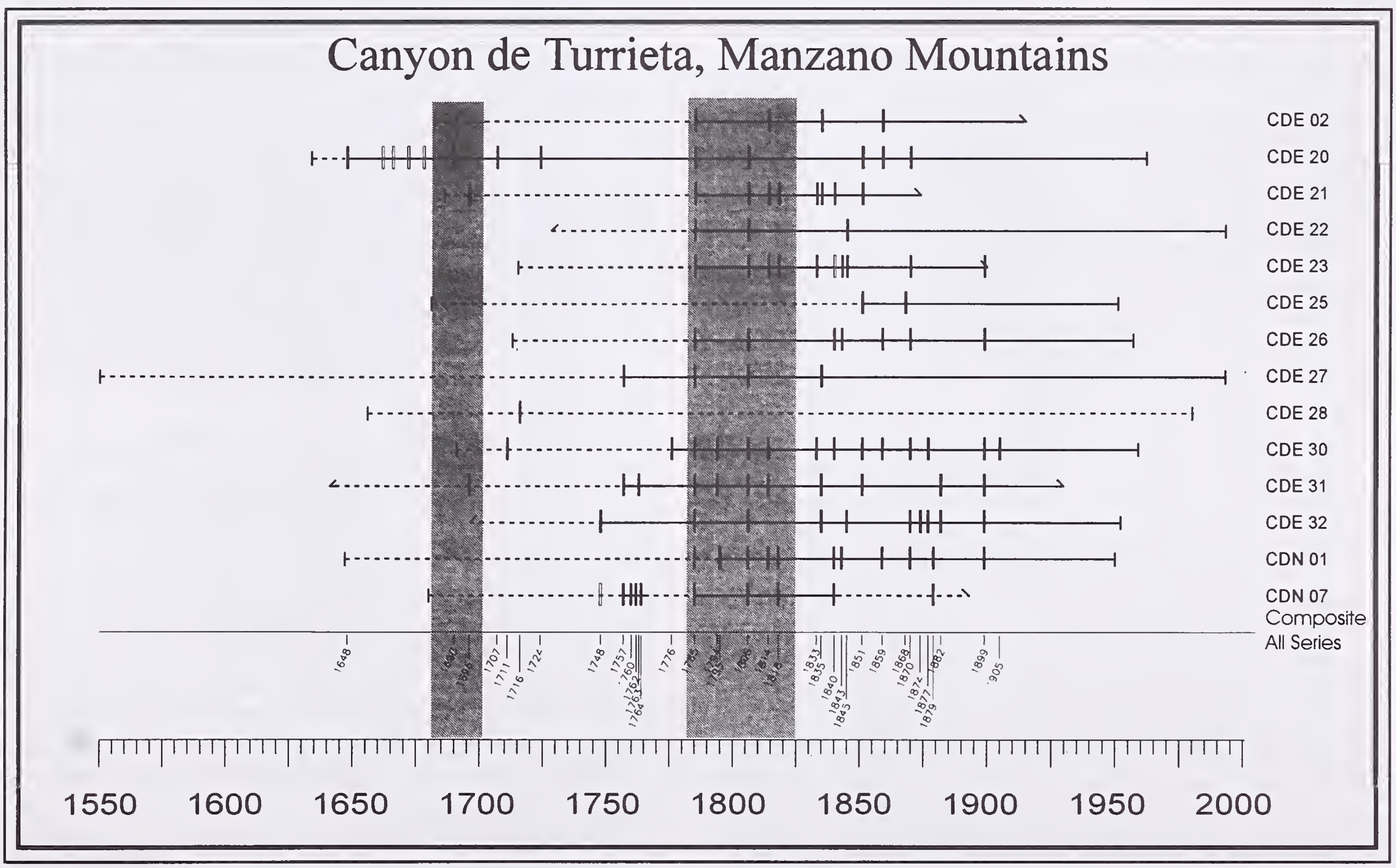

Figure 9. Fire history chart for the Manzano Mountain sites. Gray bars represent periods of reduced fire occurrence at the northern sites for comparison.

century, may have been related in some way to cultural influences. It is not clear whether fires before 1785 were generally frequent and patchy in nature, scarring few trees, or whether samples with a complete record for this period were simply not located and collected. An improvement in the record during the 17th and 18th centuries would be necessary to provide a reasonable context for interpretation. Nonetheless, surface fires continued to occur here during a period when cultural changes had already had a dramatic impact farther to the north, reducing or eliminating fire in some forested areas.

Both this site and the Capilla Peak collection exhibited a strong relationship between climate and fire occurrence. Prior years (lags -1 and -2) were typically wetter than average while fire years were dry (figure 8b). This pattern is consistent with other sites that supported an open forest structure, grassy understory, and moderate fire frequency (Swetnam and Baisan 1996).

Conclusions

All of the sites investigated during the course of this project were affected by fire over periods of centuries. Tree-ring and fire-scar evidence documents the dynamic character of this disturbance both temporally and spatially. Observed temporal shifts in fire regime parameters can be explained as the interaction of human land-use and climatic factors with internal ecosystem processes and characteristics. Relative proximity to population centers was important in the timing and extent of fire-regime alterations before the 20th century impacts of forest management.

The earliest portion of the fire-scar record suggests human-augmented fire regimes existed on the west side of the Sandia Mountains and in the Manzanita Mountains until the Pueblo Revolt of 1680. Following the resettlement of the Rio Grande valley by the Spanish around 1700, livestock grazing had a progressive impact on fire frequency, removing and disrupting fuels at the base of the mountains. Grazing was intense enough to eliminate surface fires in some areas by the later part of the 18th century, and while fire returned to more remote areas after 1830, others remained fire-free. Additional evidence for alteration of fire patterns by humans was provided by comparisons with tree-ring reconstructions of past climate. Fire occurrence in the pine and mixed-conifer forest of the Manzano Mountains was associated with dry years preceded by one or more wet years. By contrast, fire in the Sandia study areas showed no recognizable association with climate, suggesting that human influences overrode typical climatically mediated patterns. Intentional burning by humans may "force" the landscape to burn by igniting fires in places and at times that they would not otherwise have burned if subject only to the control of climate, fuel accumulation, and natural ignitions.

It is important to acknowledge that some portions of the landscape we have inherited were not pristine (e.g., unaltered by humans) a century ago or perhaps even four centuries ago. In fact, the character of the Rio Grande valley has been shaped in many ways by our predecessors' uses of it, just as current uses and needs continue to affect its development. However, the impact and influence of human use are specific in both time and space, shifting with the extent, intensity, and type of use. Landscapes are dynamic at all temporal and spatial scales, with both the biotic and abiotic components constantly in motion. Rates of change in ecosystem processes are often slow relative to human perspectives, yet dramatic shifts in fire regimes over periods of 5-10 years are evident in the records presented here.

Management Implications

Clearly, many of the resources valued by the first inhabitants remain attractive today as the population of the Rio Grande valley reaches an historic high and continued growth is expected for the foreseeable future. The needs and desires of an expanding population will continue to increase and significantly affect the resources of the region. Recreational use of remaining undeveloped areas is at an all-time high, with pressure for a variety of uses steadily increasing. Additionally, legislative mandates for endangered species protection and wilderness preservation in areas directly adjacent to large urban populations present complex challenges to managers charged with stewardship of these areas. Issues such as smoke management and threats to private property are of particular concern when the role of fire in wildland ecosystems is specifically addressed.

The legacy of centuries of cultural impact in this area remains in the current configuration of vegetation and patterns of soil erosion and channel entrenchment. New species have been added to ecosystems, including salt cedar (*Tamarix spp.*), Russian olive (*Elaeagnus angustifolia*), various grasses and weeds, pigeons, sparrows, goats, horses, chickens, cattle, and sheep. Others have become rare or have disappeared altogether. Government policies concerning resources such as fire control, timber management and fuelwood harvest, grazing regulations, and range improvements have had a tremendous impact over the last century. The New Mexico landscape we enjoy today is the complex product of the forces that have acted upon it. Particularly in this resplendent valley of the Rio Grande, flanked by the forested ramparts of the Sandia and Manzano Mountains, the imprint of generations of human activity is inescapable. One of the lessons of this

legacy is that the effect of our current actions will continue to reverberate in the landscape for decades or even centuries. The current population will inevitably continue to influence its surroundings in ways both intended and incidental for a long time.

Fire is a fundamental disturbance process in these ecosystems, one to which native vegetation and wildlife are well-adapted. Because the majority of the vegetated landscape is flammable and ignitions, both natural and human, are ever-present, we cannot expect to exclude fire from this environment. Past experience suggests that fire suppression results in exclusion of fires under moderate burning conditions but fails when conditions become severe, ensuring that large fires will occur only under the most dangerous circumstances when control is impossible and environmental impact the most severe. Current fuel accumulations in many forested areas suggest such a policy is a clear recipe for disaster. By trying to exclude a natural and beneficial process we have only managed to change the frequency and character of its occurrence. The effects of past and current uses and demands on these ecosystems will continue to influence and shape their destiny, regardless of official policy and public opinion.

Our large investment in the use of our environment, the diversity of these uses, and the number of users dictates that we be involved in its management, so that competing demands do not overwhelm the resilience of these systems. Our fears that we cannot know the effects of all our actions must not become excuses for lack of active management. We must decide as a community how we will interact with disturbances such as fire and re-assess policies such as fire exclusion that are neither desirable nor possible in most cases. If the last 10,000 years are any guide, we may conclude that fire is here to stay, and so are people. Therefore we need to make peace and forge an alliance with this elemental force.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526